भारतीय मानक
Indian Standard

IS 16648 (Part 5) : 2017

(Reaffirmed 2022)

केन्द्रित सौर तापीय — विशिष्टि

भाग 5 परीक्षण पद्धतियाँ

Concentrated Solar Thermal — Specification

Part 5 Test Methods

ICS 27.160

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भारतीय मानक ब्यूरो
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December 2017 **Price Group 5**

Renewable Energy Sources Sectional Committee, MED 4

FOREWORD

This Indian Standard (Part 5) was adopted by the Bureau of Indian Standards, after the draft finalized by the Renewable Energy Sources Sectional Committee had been approved by the Mechanical Engineering Division Council.

This standard has five parts under general title Concentrated Solar Thermal — Specification. Other parts in this series are:

Part 1	Paraboloid dish concentrator
Part 2	Scheffler concentrator
Part 3	Parabolic trough concentrator
Part 4	Non-imaging concentrator

The relevant SI units and corresponding conversion factors are given below for guidance:

Pressure 1Pa (Pascal) = 1 N/m^2
1 kgf/mm^2 = 9.806 65 MPa

The composition of the Committee responsible for the formulation of this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CONCENTRATED SOLAR THERMAL — SPECIFICATION

PART 5 TEST METHODS

1 SCOPE

1.1 This standard (Part 5) covers the determination of thermal performance of tracking concentrating solar collectors and non-tracking non-imaging concentrator (NIC).

1.2 This test method applies to one or two-axis tracking reflecting concentrating collectors and non-imaging concentrator (NIC) in which the fluid enters the collector through a single inlet and leaves the collector through a single outlet, multiple collectors in series having single inlet and outlet may also be used.

1.3 This test method is for outdoor testing only, under clear sky, quasi-steady state conditions.

1.4 This test method covers alignment, preconditioning and calculation of efficiency and analysis of data generated to give efficiency equation.

1.5 The rating of the collector is beyond the scope of this standard.

1.6 Specification of component, their sampling and analysis methods are covered in the other parts of this standard for different types of collector.

1.7 This test method does not provide a means of determining the durability or the reliability of any collector or component.

1.8 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 REFERENCE

The standard listed below contains provision which, through reference in this text, constitutes provision of this standard. At the time of publication, edition was valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate possibility of applying the most recent edition of the standard indicated below.

IS No.	*Title*
12933 (Part 3) : 2003	Flat plate collector — Specification: Part 3 Measuring instruments (*first revision*)

3 TERMINOLOGY

For purpose of this standard, following definitions shall apply:

3.1 Solar Concentrating Collector — Solar collector that uses reflectors, lenses or other optical elements to redirect and concentrate the solar radiation passing through the aperture onto an absorber.

3.2 Receiver — A part of concentrating collector to which solar radiation is finally directed comprising of absorber and any associated glass cover through which radiation is passed.

3.3 Transmittance — Ratio of the radiant flux passing through a body to that of incident radiation.

3.4 Absorptance — Ratio of the radiant flux absorbed to that of incident radiation.

3.5 Emittance — Ratio radiant existence of body to that of a black body at same temperature.

3.6 Reflectance — Ratio of the radiant flux reflected to that of incident radiation.

3.7 Aperture Area — Maximum projected area through which non-concentrated solar radiation enters the collector. Net area available for transmission of solar radiation through the outer air cover interface.

3.8 Geometric Concentration Ratio — Ratio of aperture area of a concentrating collector, to the absorber area.

3.9 Paraboloid Dish Concentrator — Point focus collector having a paraboloid dish-shaped reflector.

3.10 Parabolic Trough Collector (PTC) — Line focus collector that focuses solar radiation by means of a cylindrical reflector having a parabolic cross section.

3.11 Scheffler Dish (Point Focus Collector) — Concentrating collector that focuses solar radiation essentially to a point.

3.12 Non-Imaging Concentrator (NIC) — Concentrating collector that concentrates solar radiation onto a relatively small receiver without bringing the solar radiation to focus, that is without creating an image of the sun on the receiver.

3.13 Solar Tracker — Power driven controls operated movable two axes support which shall be employed to keep the parabolic dish oriented with respect to sun.

3.14 Collector Tilt Angle — The lower angle between the aperture plane of a solar collector and the horizontal plane.

3.15 Quasi-steady State — Solar collector test conditions when the flow rate, fluid inlet temperature, collector temperature, solar irradiance and the ambient environment have stabilized to such an extent that these conditions may be considered essentially constant.

3.16 Clear-sky Conditions — Refer to minimum level of direct normal solar irradiance of 450W/m^{2}and a variation in both direct and total irradiance within ±4 percent during the specified times before and during each test.

3.17 End Effect — In linear single axis tracking collectors, the loss of collected energy at the ends of the absorber when the direct solar rays incident on the collector make a non zero angle with respect to a plane perpendicular to the axis of collector.

3.18 Time Constant —The time required for a first order system to have its output change by 63.2 percent of its final change in output following a step change in its input.

3.19 Symbols

Q	—	Rate of energy	W
A_P	—	Aperture area	m^2
I_{bn}	—	Direct normal solar irradiance	W/m^2
I_g	—	Global solar irradiance	W/m^2
I_d	—	Diffuse solar irradiance	W/m^2
γ	—	Intercept factor	Dimensionless
ρ	—	Reflectivity	Dimensionless
α	—	Absorptivity	Dimensionless
τ	—	Transmitivity	Dimensionless
θ	—	Angle of incidence	Degree
A_1	—	Temperature dependence first degree heat loss coefficient	W/m^{2}K
A_2	—	Temperature dependence first degree heat loss coefficient	W/m^{2}K^2
T_m	—	Mean temperature at receiver	°C
T_a	—	Ambient temperature	°C
η_o	—	Optical efficiency	Dimensionless
η	—	Thermal efficiency	Dimensionless
K_{θ_T}	—	Transversal incidence angle modifier	Dimensionless
K_{θ_L}	—	Longitudinal incidence angle modifier	Dimensionless
$\dot{m}$	—	Mass flow rate of heat transfer fluid	kg/s
C_p	—	Specific heat of heat transfer fluid	J/kg°C
T_{out}	—	Temperature at exit of receiver	°C
T_{in}	—	Temperature at inlet of receiver	°C
X	—	Dryness fraction of steam	Dimensionless
C_{pf}	—	Final specific heat of water at T_f in calorimeter	J/kg°C
C_{pi}	—	Initial specific heat of water at T_i in calorimeter	J/kg°C
C_{pc}	—	Specific heat of calorimeter container	J/kg°C
h_{f1}	—	Enthalpy of water at receiver inlet	J/kg
h_{f2}	—	Enthalpy of water at receiver outlet	J/kg
M_i	—	Initial mass in calorimeter	kg
M_f	—	Final mass in calorimeter	kg
m_s	—	Mass of steam added in calorimeter	kg
Q_i	—	Initial energy in calorimeter	Joule
Q_f	—	Final energy in calorimeter	Joule
T_i	—	Initial temperature in calorimeter	°C
T_f	—	Finial temperature in calorimeter	°C
δ	—	Angle of sun declination	Degree
n	—	Day of year	Dimensionless
r	—	Radial focal distance	metre
X	—	Axial distance	metre
F	—	Focal length	metre
L_C	—	Length per collector	metre
θ_L	—	Longitudinal angle of incidence	Degree

5 SUMMARY TEST METHOD

Thermal performance is the rate of heat gain of a collect or relative to the incident solar power. This test method contains procedures to measure the thermal performance of a collector for certain well-defined test conditions. The procedures determine the response of the collector for various angles of incidence of solar radiation, and the thermal performance of the collector at various operating temperatures. The test method requires quasi-steady state conditions, measurement of environmental parameters and rate of useful heat gain (sensible and latent) by the fluid. The solar power incident on the collector is determined by the collector area, its angle relative to the sun, and the irradiance measured during the test.

6 MEASURINGINSTRUMENTS

6.1 Measurements of Solar Radiation

Class I or better, pyranometer(s) shall be used to measure the solar radiation. Before each test the pyranometer(s) should be checked for dust, soiling etc on the outer dome and it should be cleaned, if necessary. Class I or better pyranometer(s) equipped with a shading ring or alternatively a pyrheliometer together with a pyranometer shall be used to measure the diffuse short-wave radiation.

6.2 Temperature Measurements

Three temperature measurements are required for solar collector testing. These are the fluid temperature at the collector inlet, the fluid temperature at the collector outlet, and the ambient air temperature. The temperature of the heat transfer fluid at the collector inlet and outlet shall be measured to a standard uncertainty of 0.1 K [*see* IS 12933 (Part 3)].

6.3 Flow Rate Measurement

Mass flow rates may be measured directly or, alternatively, if the density is known, they may be determined from measurements of volumetric flow rate and temperature. The standard uncertainty of the liquid flow rate measurement shall be within ± 1 percent of the measured value, in mass per unit time. The flow meter shall be calibrated over the range of fluid flow rates and temperatures to be used during collector testing. For measuring instruments specification and procedures [*see* IS 12933 (Part 3)].

7 PREPARATION OF APPARATUS

7.1 The collector shall be installed and aligned properly according to a test method approved by the manufacturer.

7.2 Collector surfaces exposed to the environment shall be cleaned at the beginning of each test day according to the manufacturer's recommended procedures.

7.3 The geographical location (latitude and longitude) of the collector shall be determined and reported to an accuracy of ±0.1°. Where applicable, the orientation of any ûxed collector axis shall be measured to an accuracy of ±0.1 percent and reported.

7.4 The pyrheliometer and pyranometer shall be inspected at the beginning of each day at which time the outer glass surface shall be cleaned and dried if dirt or moisture is present. Any evidence of moisture or debris in the interior of the instrument shall be cause to remove it from service.

7.5 Calibration of instruments shall be checked before starting the tests.

8 TEST CONDITIONS

8.1 Ambient Conditions

The following test conditions shall be observed for conducting the efficiency and incident angle modifier tests:

a) The direct normal solar irradiance (I_{bn}) shall not be less than 450 W/m^2.

b) The average value of the surrounding air speed shall be below 5 m/s.

c) The ambient temperature will vary place to place, however care should be taken so that the fluid in the piping and receiver does not get condensed/frozen.

The system shall be tested over its operating temperature range under clear sky condition for determining its efficiency. The measurements are carried out under quasi steady state conditions as shown in Table 1.

Table 1 Quasi-steady State Conditions

(*Clauses* 8.1)

Sl No.	Parameter	Deviation from the Mean Value Over the Test Period
(1)	(2)	(3)
i)	The normal beam radiation	± 4 percent during the interval of measurement
ii)	Surrounding air temperature	± 1°C
iii)	Fluid mass flow rate	The flow rate shall be held stable to within 1 percent of the set value during each test period and shall not vary by more than ± 10 percent of the set value from one test period to another
iv)	Receiver fluid inlet temperature	± 0.2°C or 1 percent of change in temperature (Δt)

8.2 Quasi-steady State Conditions

A collector may be considered to have been operating in quasi-steady state conditions over a given test period if none of the experimental parameters deviate from the mean values over the test period by more than the limits given below. For the purpose of establishing that a quasi-steady state exists, average values of each parameter taken over successive periods of 60s shall be compared with the mean value over the test period.

9 TEST PROCEDURE

Start operation of the collector as per the procedure given by manufacturer and record data. Data points which satisfy the conditions given under quasi-steady state conditions shall be obtained for at least four inlet temperatures spaced evenly over the operating range of receiver. One inlet temperature shall be selected such that the mean fluid temperature in the receiver lies within ± 3°C of the ambient temperature in order to obtain an accurate determination of optical efficiency. At least four independent data points shall be obtained for each fluid inlet temperature to collect a total of 16 data points.

10 MEASUREMENTS

The following measurement shall be obtained:

a) Collector aperture area (A_p),
b) Global solar irradiance (I_g),
c) Diffused solar irradiance at the collector aperture (I_d),
d) Direct normal irradiance (DNI) (I_{bn}),
e) Surrounding wind speed,
f) Surrounding air temperature (T_a),
g) Temperature of heat transfer fluid at the receiver inlet (T_{in}),
h) Temperature of heat transfer fluid at the receiver outlet (T_{out}),
j) Mass flow rate of the heat transfer fluid ($\dot{m}$), and
k) Pressure of fluid in receiver.

11 COMMENCEMENT OF DATA ACQUISITION

The data acquisition shall be commenced after start of the system, typically 3 h before and after solar noon shall be used for data collection. The data shall be used for analysis during the quasi-steady state. The data shall be collected at minimum 10 s interval. A data point for any variable shall be the average of at least 10 observations.

12 BASIC PERFORMANCE EQUATION

The performance of CST based solar collector operating under steady state conditions can be described by the following equation:

$$\frac{Q}{A_p} = I_{bn} \times \gamma \times \rho(\alpha\tau) \times \mathrm{Cos}\theta - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2$$

The values ρ, α, τ are for normal incidence of solar radiation. In order to predict the system performance at other incident angles, as would be the case with actual field installations, multiplying factor called the incident angle modifier ($K_{\theta T}$ and $K_{\theta L}$) are introduced in equation 1. Where $K_{\theta L}$ is the longitudinal incidence angle modifier and $K_{\theta T}$ is transversal incidence angle modifier. Also the effect of angle of incidence on the intensity of beam radiation is introduced in the equation in form of Cosθ, where θ is the angle of incidence.

$$\frac{Q}{A_p} = I_{bn} \times \eta_o \times \mathrm{Cos}\theta \times K_{\theta T} \times K_{\theta L} - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2$$

12.1 Incident Angle Modifier

The intent of following procedure is to generate sufficient incident angle modifier data $K_{\theta L}$ and $K_{\theta T}$ to characterized the collector thermal performance over the full range of actually operating angles that will be encountered.

12.1.1 Longitudinal incidence angle modifier $K_{\theta L}$ can be calculated with the angle of incidence caused by declination of sun.

12.1.2 Transversal incidence angle modifier $K_{\theta T}$ can be calculated with angle of incident of sun movement from morning to evening.

12.2 Useful Heat Gain

12.2.1 *Thermic Fluid / Water (Without Phase Change)*

The useful energy extracted by the receiver for hot water or thermic fluid based system may be expressed as follows:

$$Q = \dot{m} \times C_p (T_{out} - T_{in})$$

where, $\dot{m}$ is the mass flow rate of heat transfer fluid in kg/s, C_p is the specific heat of the heat transfer fluid in J/(kg °C) and T_{out} and T_{in} are the temperature of heat transfer fluid leaving and entering the collector respectively in °C.

12.2.2 *Steam (Phase Change)*

A calorimeter is equipment which measure heat contents of wet, dry or superheated steam. As per design water is taken in calorimeter at room temperature. The solar wet steam shall be injected in to the calorimeter. The increase in temperature and level of water due to condensation of steam is measured to get the heat content of steam.

The useful energy extracted by the receiver for steam based system and collected in calorimeter are expressed as follows:

$$\begin{aligned} Q &= Q_f - Q_i \\ Q_f &= M_f \times C_{pf} \times T_f + C_{pc} \times T_f \\ Q_i &= M_i \times C_{pi} \times T_i + C_{pc} \times T_i \\ Q &= M_f \times C_{pf} \times T_f - M_i \times C_{pi} \times T_i + C_{pc} (T_f - T_i) \end{aligned}$$

where

Q = useful heat gain,

Q_f = heat content of calorimeter after the test,

Q_i = heat content of calorimeter before the test, and

C_{pc} = heat capacity of the container of the calorimeter which shall be determined for the specific calorimeter design.

12.3 Efficiency Equation

The thermal efficiency solar collector system is defined as a ratio of the actual useful energy collected to that of the solar energy intercepted by the solar collector, then the efficiency of the CST based concentrator system may be defined as follows:

$$\eta = \eta_o - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times I_{bn} \left(\frac{T_m - T_a}{I_{bn}}\right)^2$$

or

$$\eta = \eta_o - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times \frac{(T_m - T_a)^4}{I_{bn}}$$

The later equation is used for temperature more than 200°C.

13 COMPUTATION OF THERMAL EFFICIENCY

The instantaneous efficiency η shall be calculated from the following expression:

$$\eta = \frac{\dot{m} \times C_p (T_{out} - T_{in})}{I_{bn} \times A_p}$$

An appropriate value of C_P at mean fluid temperature shall be used in the above expression. If $\dot{m}$ is obtained from volumetric flow rate measurement, then the density shall be determined for the temperature of the fluid in the flow meter.

The instantaneous efficiency shall be presented graphically as a function of $\left(\frac{T_m - T_a}{I_{bn}}\right)$. All the data points shall be plotted along with a statistical curve fitting using the least square

14 COMPUTATION OF OPTICAL EFFICIENCY

The optical efficiency shall be calculated from the equation given in **12.3**.

For calculating optical efficiency of the system a graph is plotted between instantaneous efficiency *versus* $\Delta T/I_{bn}$. The intercept of curve on Y-axis is optical efficiency. Alternatively data is collected by maintaining near zero heat loss condition by selecting inlet temperature such that the mean fluid temperature in the receiver lies within ± 3°C of the ambient temperature ($T_m = T_a$).

15 COMPUTATION OF HEAT LOSS COEFFICIENTS (a_1, a_2,)

The test shall be conducted at at least four inlet temperatures spaced evenly over the operating temperature range of solar collector to determine the values of a_1 and a_2. Multiple linear regression (MLR) shall be used to determine a_1 and a_2 using the data collected.

16 DETERMINATION OF INCIDENT ANGLE MODIFIER

Determination of incident angle modifier shall be done by collecting data on heat gain by the mass flow rate specific heat product (M_{cp}) and temperature difference between inlet and outlet of the collector. While maintaining the collector within ± 2.5°C all the angle of incidence specified bellow, the inlet temperature of heat transfer fluid shall be maintain within 1°C. The collector shall be made to track within the allowable tracking error. The angle of incidence may be measured or calculated using sun position angle. Repeat above for incident angle from 0 to 60 or as specified by manufacturer. Between 3 to 5 number of angle of incident shall be chosen to get the effect of angle on performance.

Incident angle modifiers (IAM) can be determined from the following equation:

$$K(\theta) = \frac{\eta_o(\theta)}{\eta_o(\theta = 0)}$$

The efficiency values are determined in pairs, where each pair includes a value of efficiency before solar noon and second value after solar noon. The average incident angle between the collector and the solar beam for both data points is the same. The efficiency of collector for the specific incident angles should be considered equal to average of two values. Data shall be collected for incident angle of about 0°, 30°, 45° and 60°.

17 MODIFIED EQUATION FOR DIFFERENT CST's

17.1 Paraboloid Dish and Fresnel Dish Concentrator

Paraboloid dish and fresnel dish concentrator are moving point focus, dual axis tracking systems. Due to dual axis tracking the reflector is always normal to solar radiation thus making the value of equal to unity. The performance of the system can be expressed by following equation:

$$\frac{Q}{A_p} = I_{bn} \times \eta_o - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^4$$

17.2 Parabolic Trough

Parabolic trough is a moving line focus, single axis tracking system. It tracks the sun from morning to evening. Due to single axis tracking, the value of equals to unity. Also, since the system doesn't track the sun's declination, some fraction of a receiver tube will not receive solar radiation due to longitudinal angle of incidence. This loss is known as end loss. The performance of the system can be expressed by following equation:

$$\frac{Q}{A_\text{p}} = I_\text{bn} \times \eta_\text{o} \times (1 - \text{End loss}) \times K_{\theta\text{L}} - a_1 (T_\text{m} - T_\text{a}) - a_2 \times (T_\text{m} - T_\text{a})^2$$

where

$$\text{End loss} = \frac{r}{L_\text{C}} \times \tan \theta_\text{L}$$

For determination of incidence angle modifier, procedure given in **17** shall be used. It would be recommended to test the system during the period when longitudinal angle of incidence is less than 30° so that the effect of is negligible on the system efficiency.

17.3 Scheffler Reflector

Scheffler reflector is a fixed point focus, polar axis tracking system. It tracks the sun from morning to evening. Due to polar axis tracking, the value of Cosθ equals to unity. The performance of the system can be expressed by following equation:

$$\frac{Q}{A_\text{p}} = I_\text{bn} \times \eta_\text{o} \times \text{Cos}\theta \times K_{\theta\text{L}} - a_1 \times (T_\text{m} - T_\text{a}) - a_2 \times (T_\text{m} - T_\text{a})^2$$

where

$$\text{Cos}\theta = \text{Cos}\left(43.23° - \frac{\text{solar declination}}{2}\right)$$

The equation with least error (<0.035°) is used for the determination of solar declination for any day of the year.

$$\delta = 180/\pi \left[(0.006\,918 - 0.399\,912) \frac{\text{Cos}\,(n-1)2\pi}{365} + 0.070\,257 \frac{\text{Sin}(n-1)2\pi}{365} - 0.006\,758 \frac{\text{Cos}2(n-1)2\pi}{365} + 0.000907 \frac{\text{Sin}\,(n-1)2\pi}{365} - 0.002\,679 \frac{\text{Cos}3(n-1)2\pi}{365} + 0.001 \frac{48\ \text{Sin}\ 3\ (n-1)2\pi}{365} \right]$$

where n is the day of the year.

Incident angle modifier will always be there throughout year. The optical efficiency on 22nd of December can be taken as reference for determining the value of throughout the year.

$$K(\theta) = \frac{\eta_\text{o}(\theta)}{\eta_\text{o}(\text{on 22nd December})}$$

The report shall mention the date of testing in order to consider the effect of $K(\theta)$.

17.4 Non-imaging Concentrator (NIC)

NIC is a non-tracking concentrating solar thermal technology. NIC works with global irradiance instead of direct normal irradiance. The performance of the system can be expressed by following equation:

$$\frac{Q}{A_\text{p}} = I_\text{g} \times \eta_\text{o} \times \text{Cos}\theta \times K_{\theta\text{T}} \times K_{\theta\text{L}} - a_1 \times (T_\text{m} - T_\text{a}) - a_2 \times (T_\text{m} - T_\text{a})^2$$

While $K_{\theta\text{T}}$ needs to be determined, effect of $K_{\theta\text{L}}$ can be neglected if the system is mounted at the latitude of that location

18 TEST REPORT

The following information should be reported in the test report.

Collector Information	
1.	Technology Type
2.	Manufacturer
3.	Model and Serial Number
4.	Dimension and Area
5.	Receiver Data — Shape, dimensions, material, coatings.
6.	Reflector or Refractor — Shape, dimensions, material.
7.	Glazings — Shape, dimensions, materials
8.	Tracking and drive mechanism description as applicable,

Test Data and Results	
9.	Location — Latitude, Longitude
10.	Date
11.	Collector orientation, mounting.
12.	Ambient conditions — Solar radiation, ambient temperature, operating temperature etc.
13.	Operating conditions — Operating temperature, pressure, flow etc.
14.	Calculated optical efficiency
15.	Calculated first order heat loss coefficient (a_1)
16.	Calculated second order heat loss coefficient (a_2)
17.	Calculated thermal efficiency at different mean temperature of receiver
18.	Calculated incidence angle modifier at different incidence angles (graph)
19.	Performance graph between efficiency

ANNEX B

(*Foreword*)

COMMITTEE COMPOSITION

Renewable Energy Sources Sectional Committee, MED 04

Organization	*Representative(s)*
Ministry of New and Renewable Energy, New Delhi	Shri Sohail Akthar (***Chairman***)
Biogas Forum India, New Delhi	Dr A. R. Shukla
Bipin Engineers Pvt Ltd, Pune	Shri H. S. Revankar Shri A. K. Baikerikar (*Alternate*)
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The Energy and Resources Institute, New Delhi	Shri Girishri garud Dr Ishan Purohit (*Alternate*)
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Solar Thermal Energy Sub-Committee, MED 04:1

Regional Test Centre, Indore	Dr S. P. Singh (***Convener***) Prof R. N. Singh (*Alternate*)
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PART 5 TEST METHODS

(*Page* 2, *clause* **3.19**, *symbols* A_1, A_2) — Substitute the following for the existing:

‘a_1 — Temperature dependence first degree heat loss coefficient W/m^2K
a_2 — Temperature dependence second degree heat loss coefficient W/m^2K^2’

(*Page* 5, *clause* **12.3**, *equations*) — Substitute:

‘$$\eta = \eta_o \times Cos\ \Theta \times K_{\theta_T} \times K_{\theta_L} - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times I_{bn} \left(\frac{T_m - T_a}{I_{bn}}\right)^2$$

or

$$\eta = \eta_o \times Cos\ \Theta \times K_{\theta_T} \times K_{\theta_L} - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times \frac{(T_m - T_a)^4}{I_{bn}}$$’

for

‘$$\eta = \eta_o - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times I_{bn} \left(\frac{T_m - T_a}{I_{bn}}\right)^2$$

or

$$\eta = \eta_o - a_1 \left(\frac{T_m - T_a}{I_{bn}}\right) - a_2 \times \frac{(T_m - T_a)^4}{I_{bn}}$$’

(*Page* 6, *clause* **17.2**, *third sentence*) — Substitute the following for the existing:

‘Due to single axis tracking, the value of K_{θ_L} equals to unity.’

(*Page* 6, *clause* **17.2**, *equation*) — Substitute:

‘$$\frac{Q}{A_P} = I_{bn} \times \eta_0 \times \mathrm{Cos}\Theta \times (1 - \text{End loss}) \times K_{\theta_L} - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2$$’

for

‘$$\frac{Q}{A_P} = I_{bn} \times \eta_0 \times (1 - \text{End loss}) \times K_{\theta_L} - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2$$’

(MED 04)

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